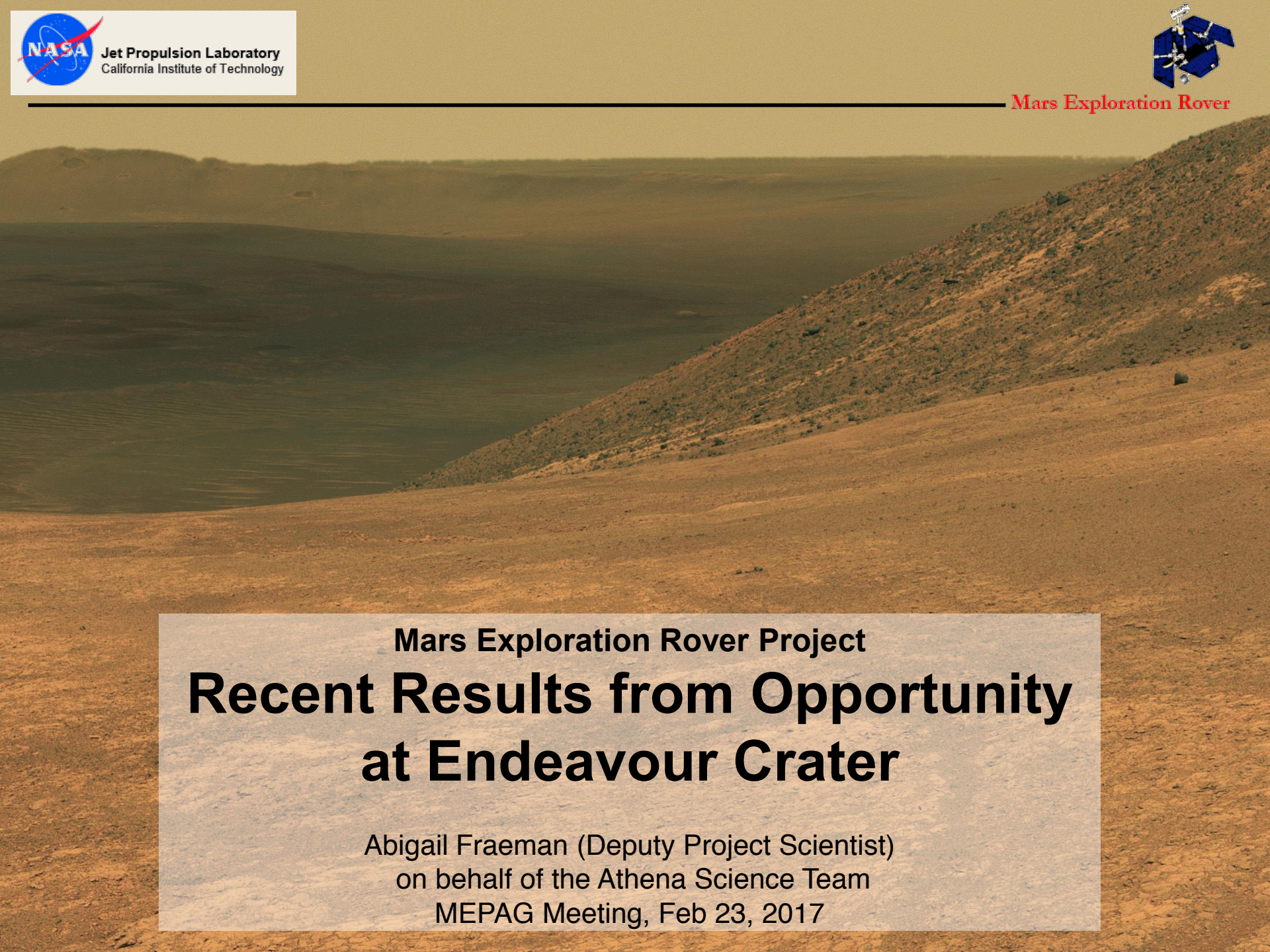



Mars Exploration Rover Project

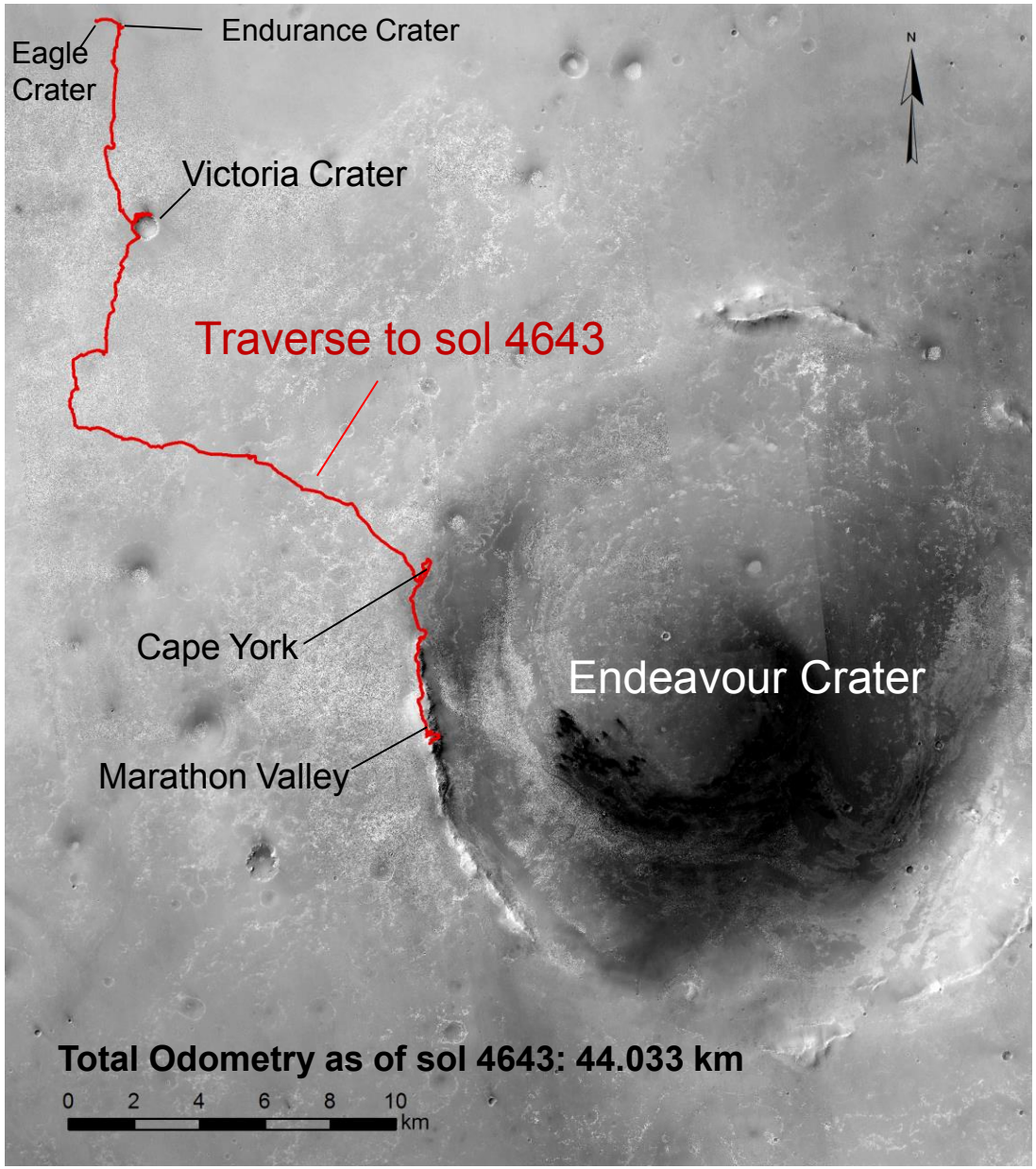
# Recent Results from Opportunity at Endeavour Crater

Abigail Fraeman (Deputy Project Scientist)
on behalf of the Athena Science Team

MEPAG Meeting, Feb 23, 2017

# Opportunity Context






- Opportunity recently entered its 10th extended mission and celebrated 13+ years operating on Mars
- Sol 4643 odometry = 44.033 km
- Vehicle in good health:
  - Pancam, MI, and APXS fully functional; RAT grind bit still available for use
  - Recent solar panel cleaning event (sol 4637)
  - Right front wheel permanently rotated inward 8° and IDD joint 1 not functional but can still effectively reach desired science targets
  - Continue to operate in persistent RAM mode

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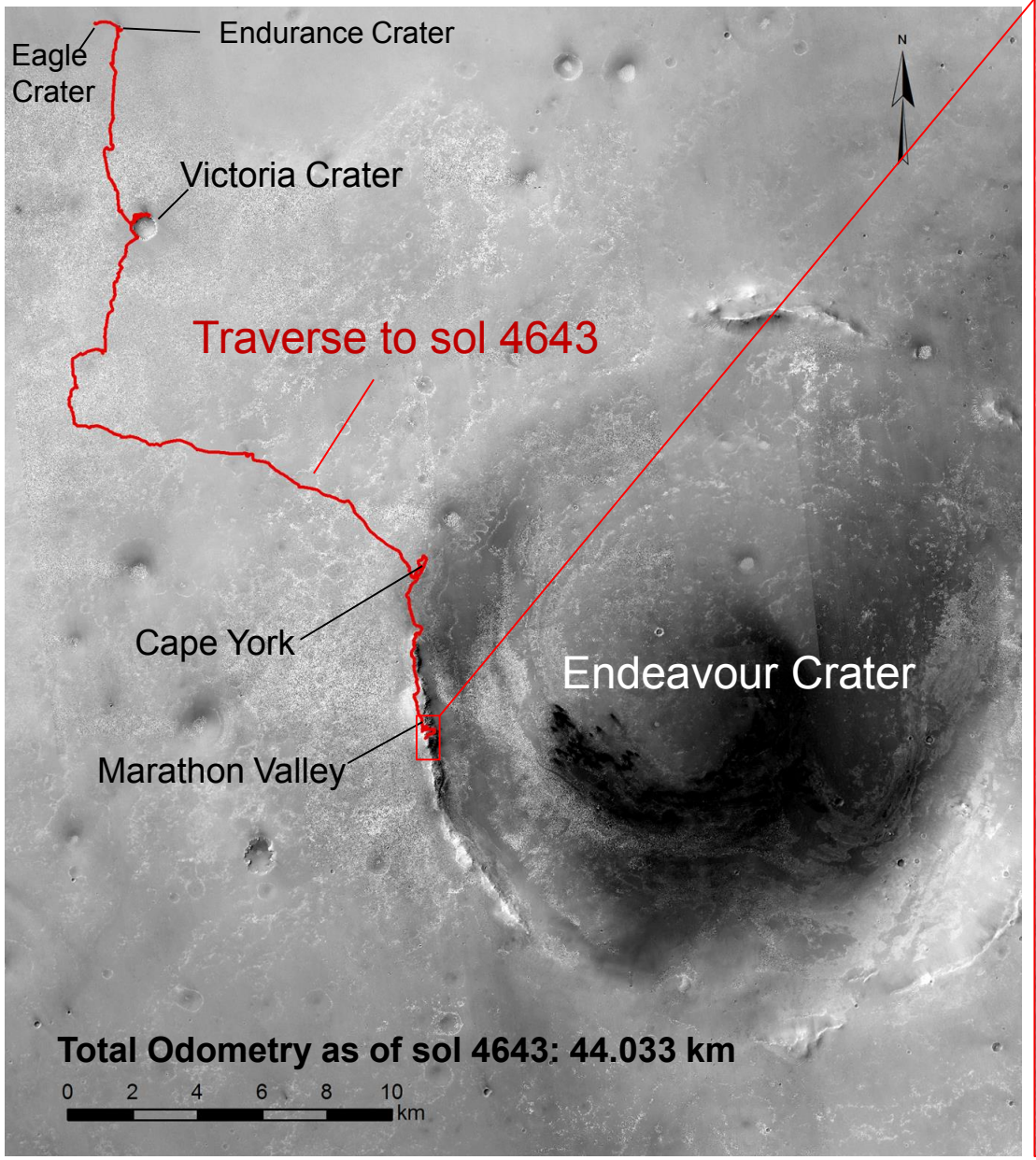
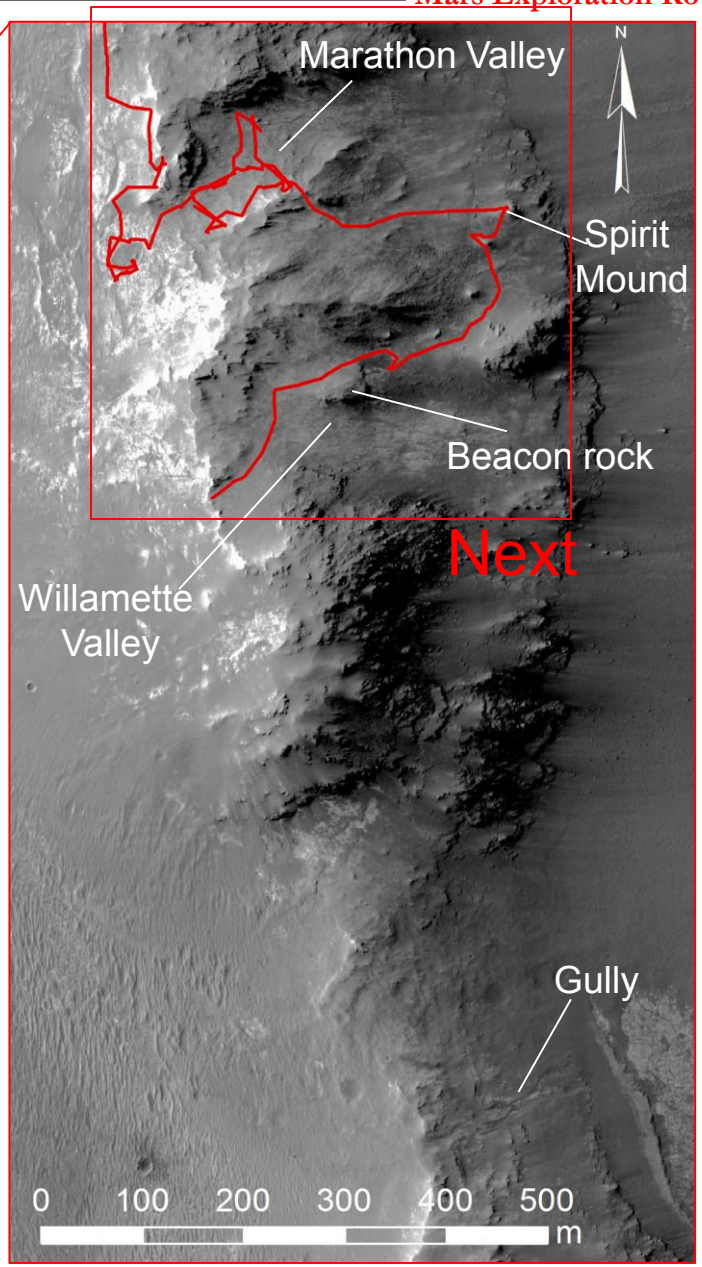
# Opportunity Context

Mars Exploration Rover



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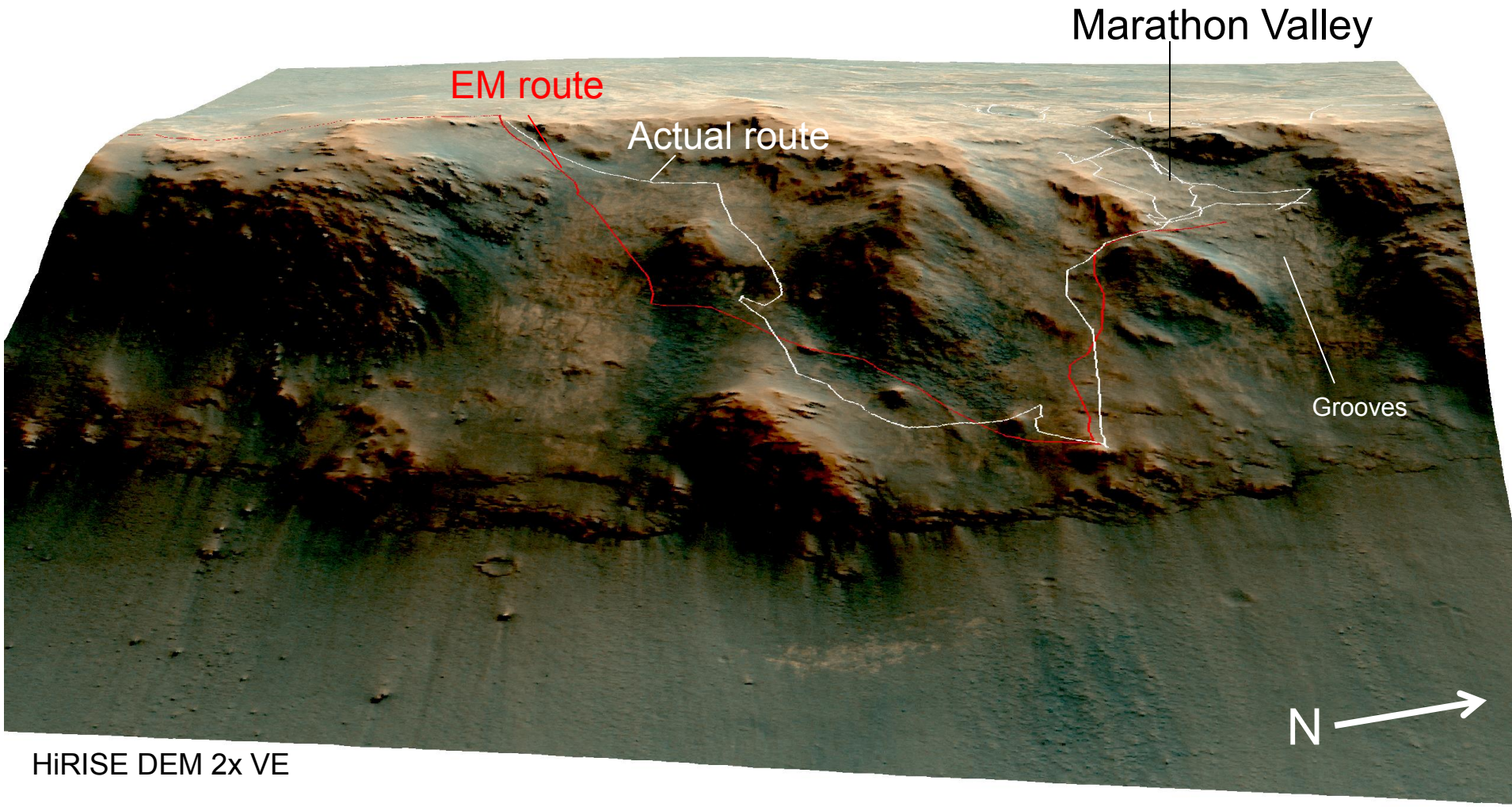
# Marathon Valley

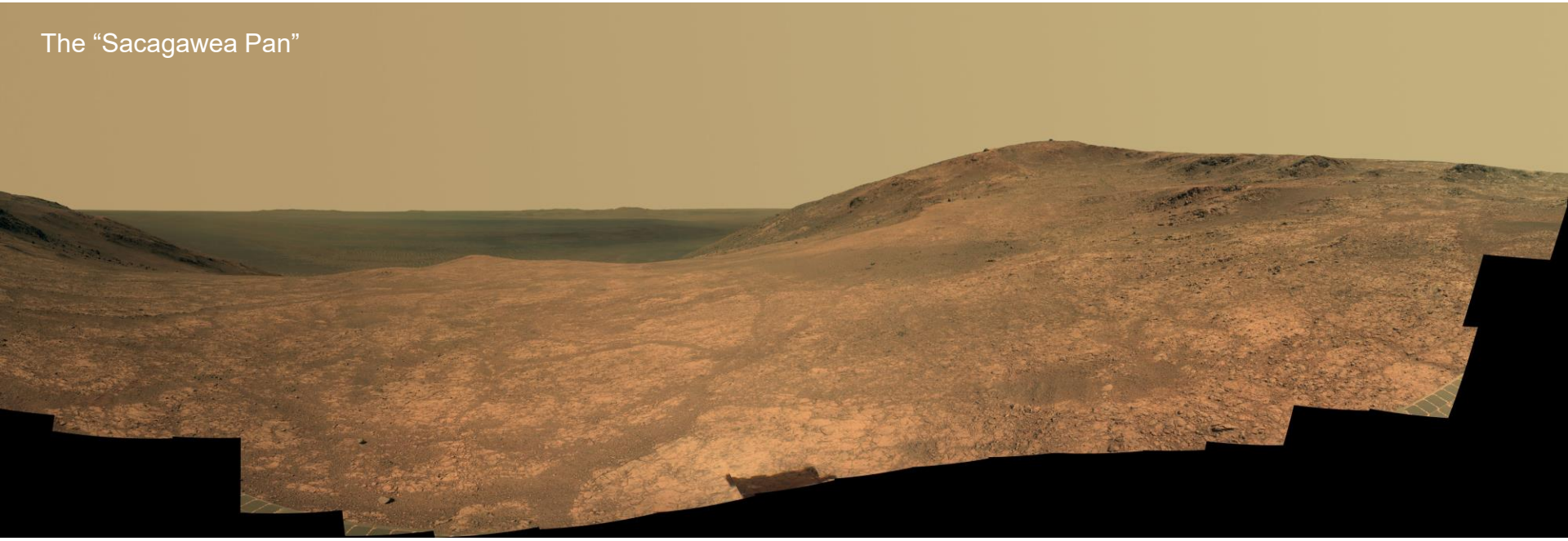
Mars Exploration Rover




Opportunity thoroughly explored the floor of Marathon Valley after CRISM showed evidence for $Fe^{3+}$-$Mg^{2+}$ smectites in the area (Wray et al., 2009; Fox et al., 2016)

# Marathon Valley

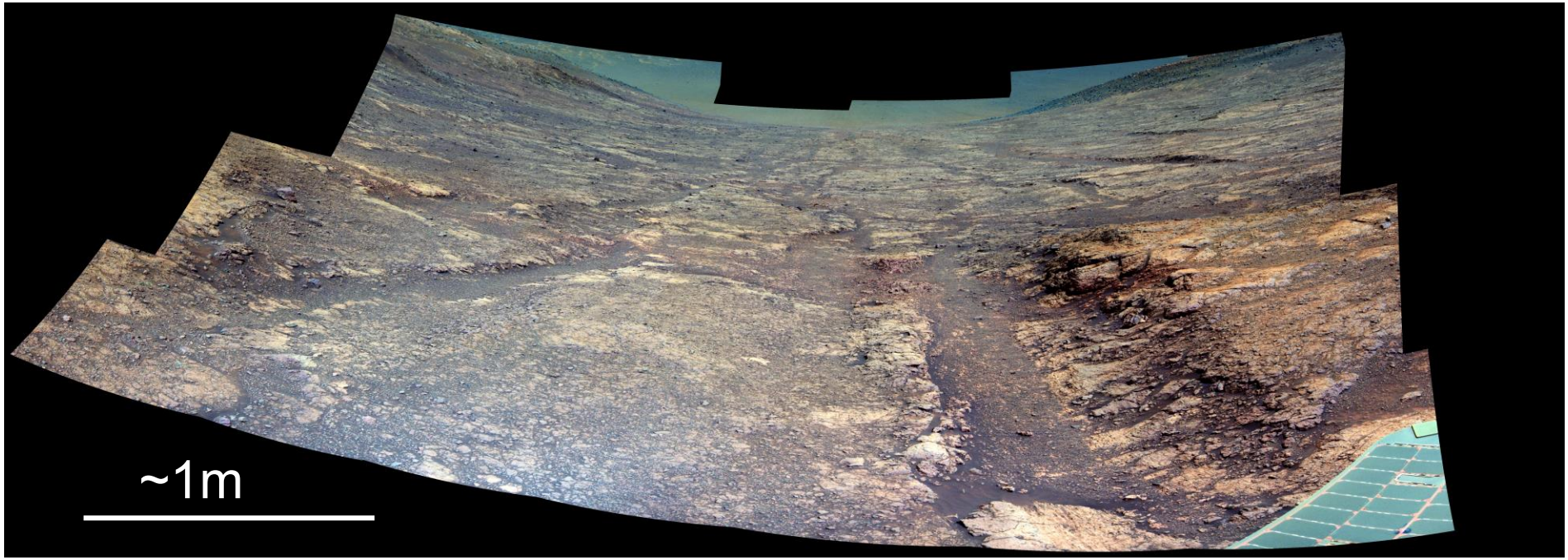





- Opportunity characterized smectite-bearing outcrops; likely formed in low W:R ratios with isochemical weathering (Fox et al., *GRL*, 2016)
- Also found fractures that contained evidence of localized, more intense leaching to produce pebbles enriched in Al and Si (Mittlefehldt et al, *GSA*, 2016) and multiple sulfate-bearing phases (Arvidson et al., *LPSC*, 2017; Farrand et al., *LPSC,* 2017)

# Grooves






- Opportunity imaged the top of a series of grooves running down the rim of Endeavour crater shortly before departing Marathon Valley
- Low average slope of the groves (~22˚) suggest formed via erosion by aeolian, fluival, or debris flow processes (Fraeman et al., *LPSC,* 2017)
- Observations will be compared with future observations of similar features further south along Endeavours' rim

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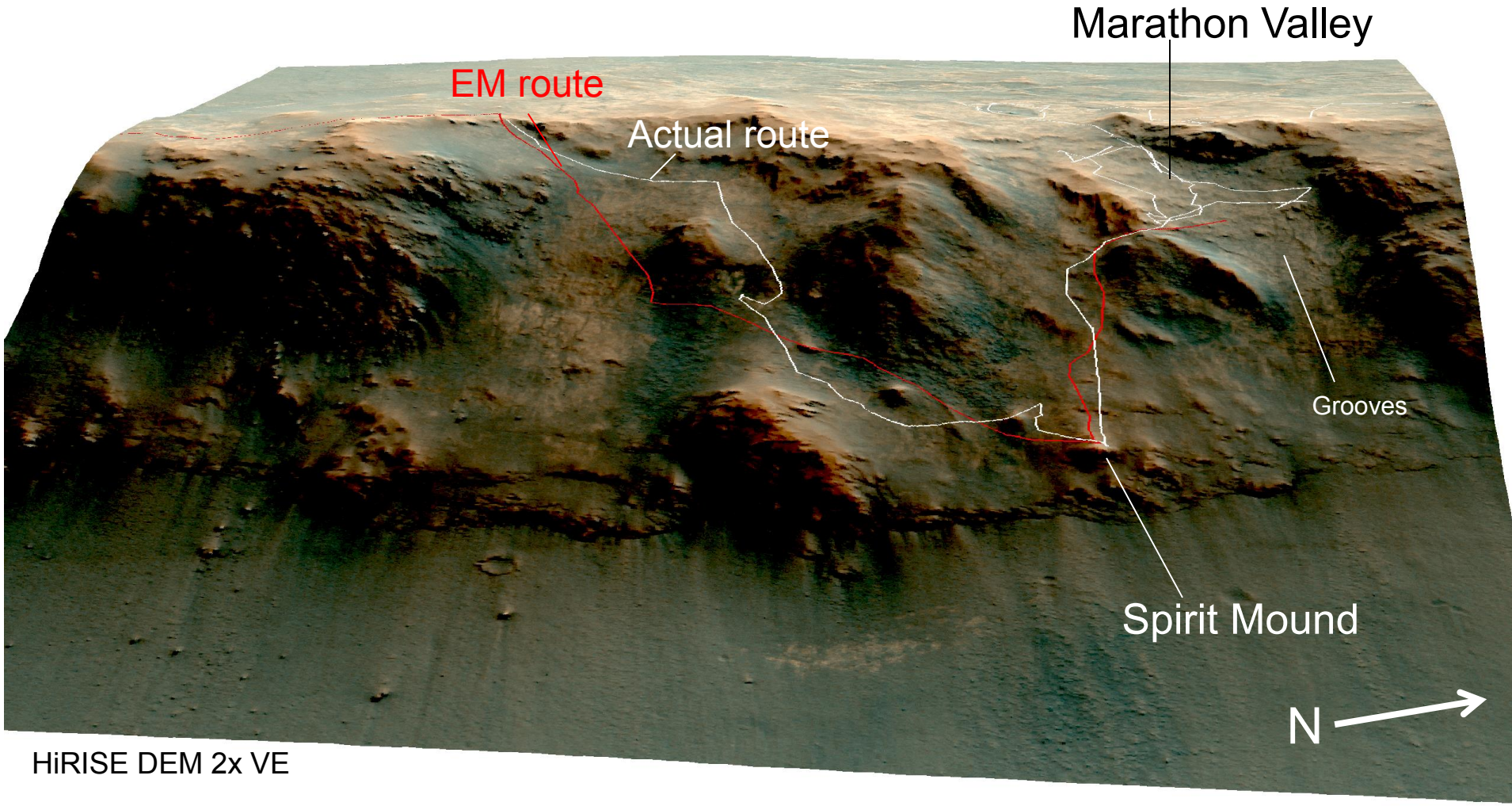
# Investigation at Spirit Mound

Mars Exploration Rover

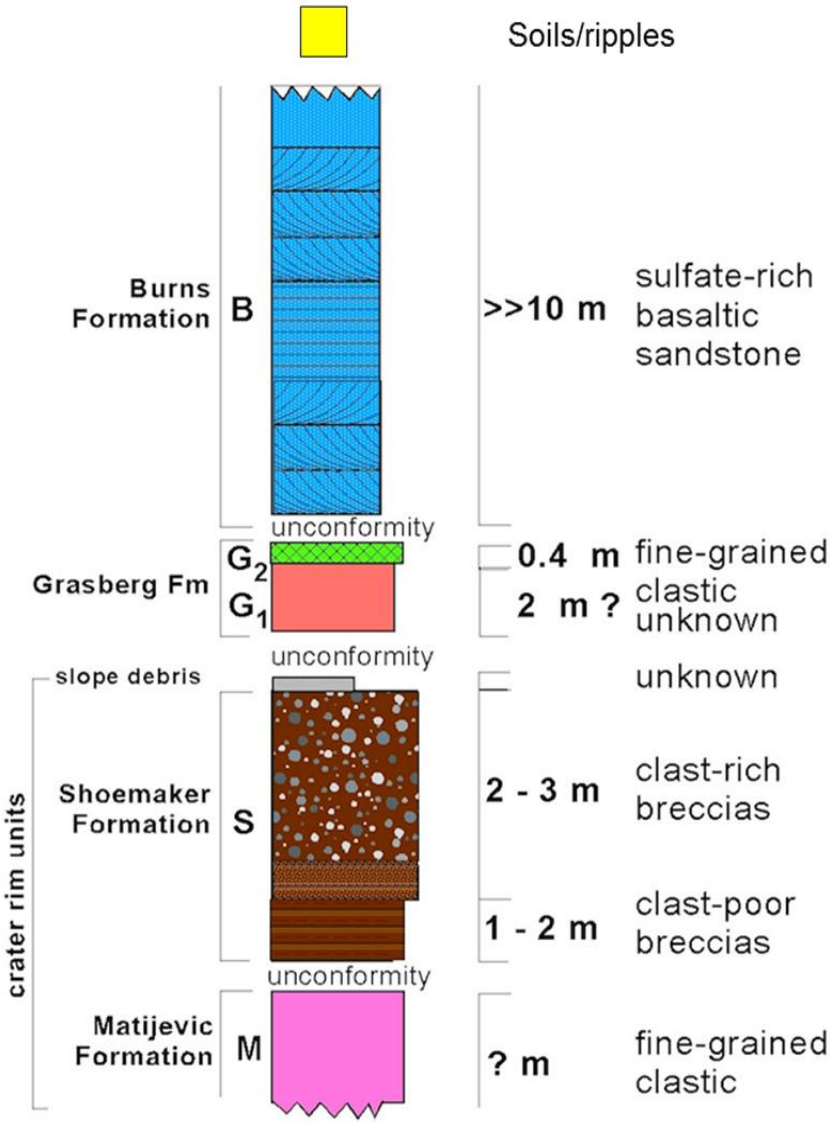



HiRISE DEM 2x VE

Spirit Mound represents lowest elevation location visited by Opportunity on this segment of Endeavour rim

# Searching for Matijevic Formation



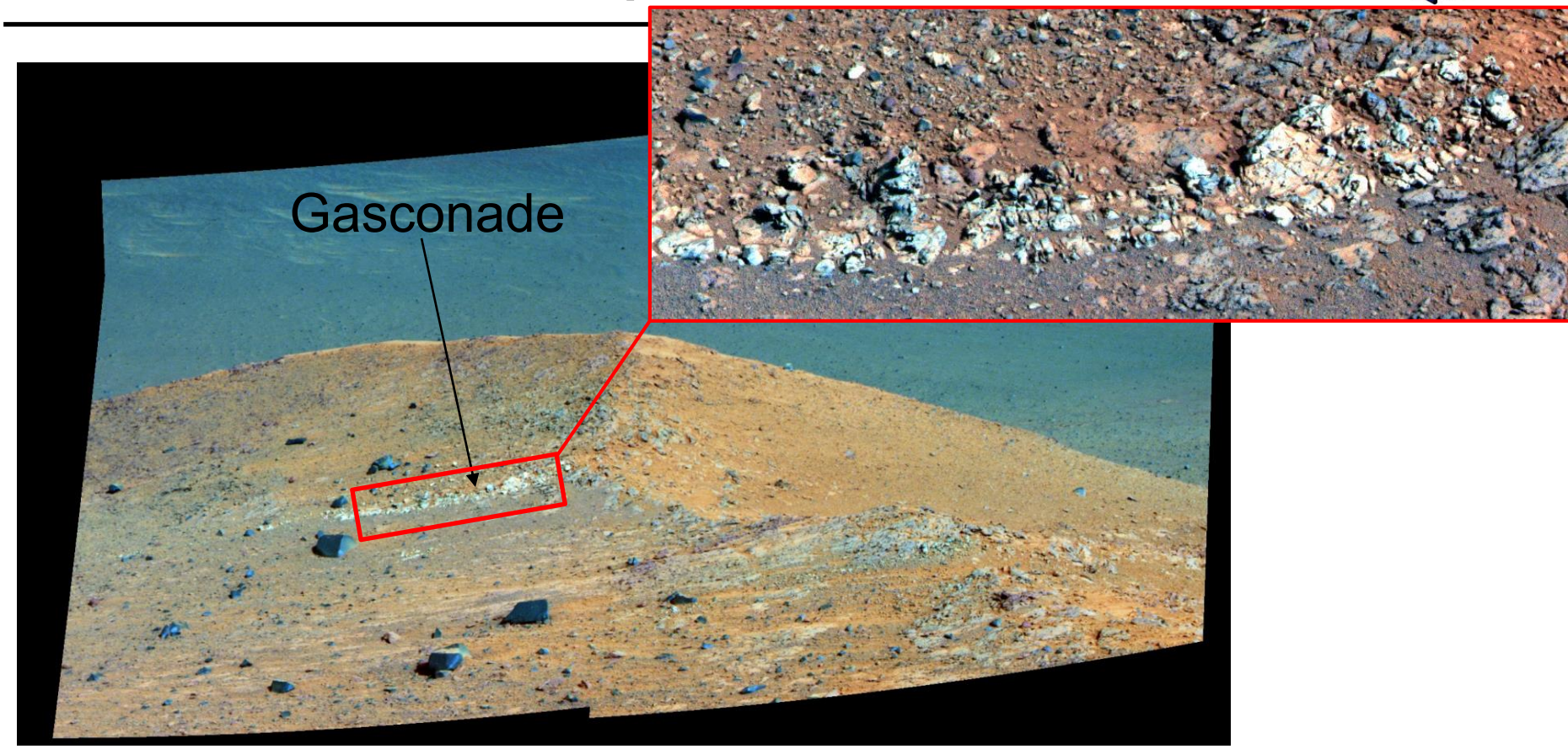



Crumpler et al., 2015


Unconformity between Shoemaker and Matijevic Formation outcrops at Cooper Cliffs.

- Matijevic formation are oldest rocks seen by Opportunity
- Contain spherules, ferric smectites + leaching towards Al-rich component in fracture zones (Arvidson et al., 2014; Clark et al., 2016)
- Last seen on inboard side of Cape York but limited areal extend precluded understanding of depositional environment

# Spirit Mound



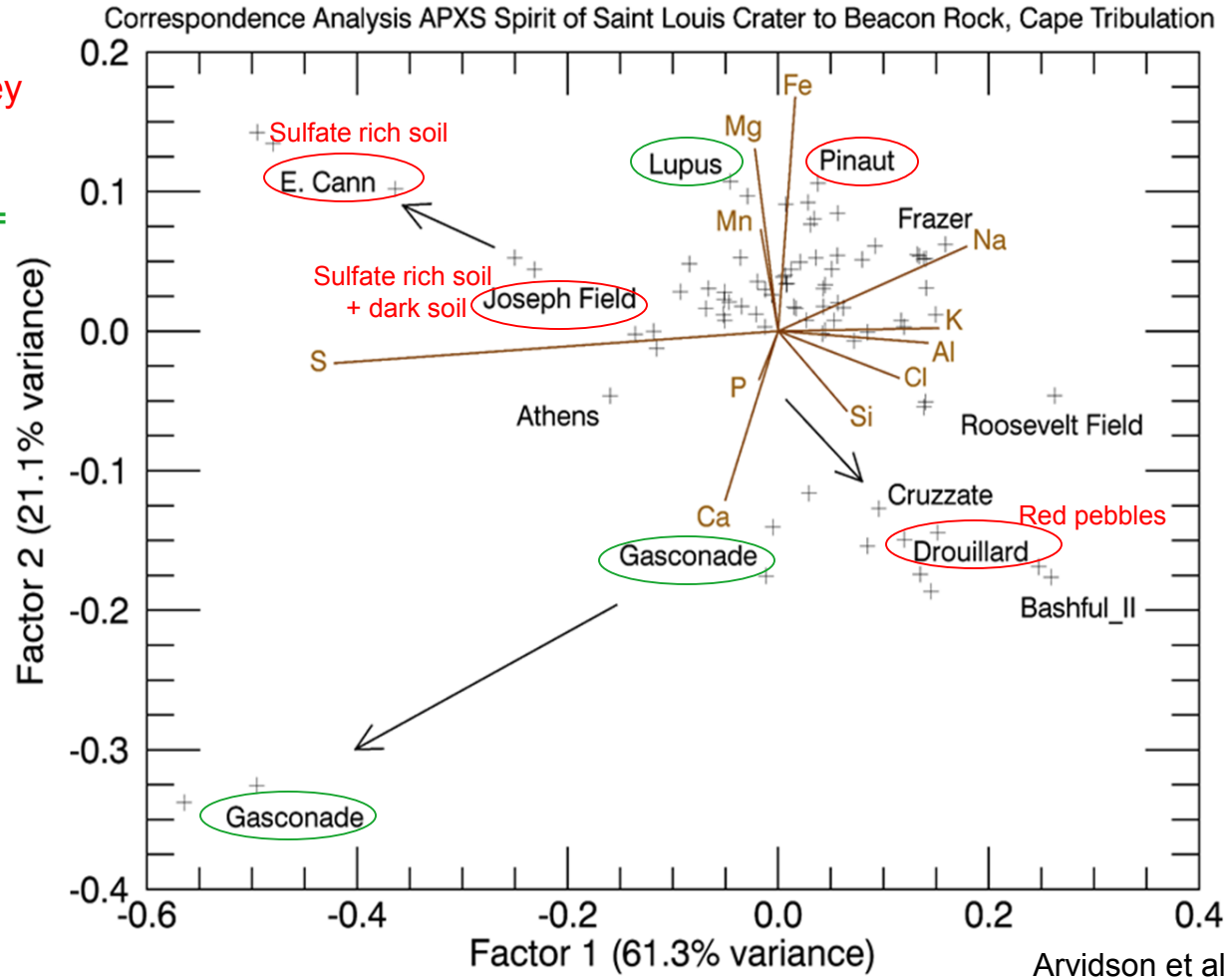

- Spirit Mound contained only Shoemaker formation breccia but with unique chemistries
- Particularly target Gasconade → enhanced in Ca + S, indicating another type of fracture controlled aqueous alteration in the Shoemaker formation (Arvidson et al., LPSC, 2017)
- Multispectral observations showed negative NIR slopes, possibly indicating $H_2O$ overtone (Farrand et al., LPSC, 2017)

# Spirit Mound



Red circles = Marathon Valley floor targets

Green circles = Spirit Mound targets




Arvidson et al., LPSC, 2017

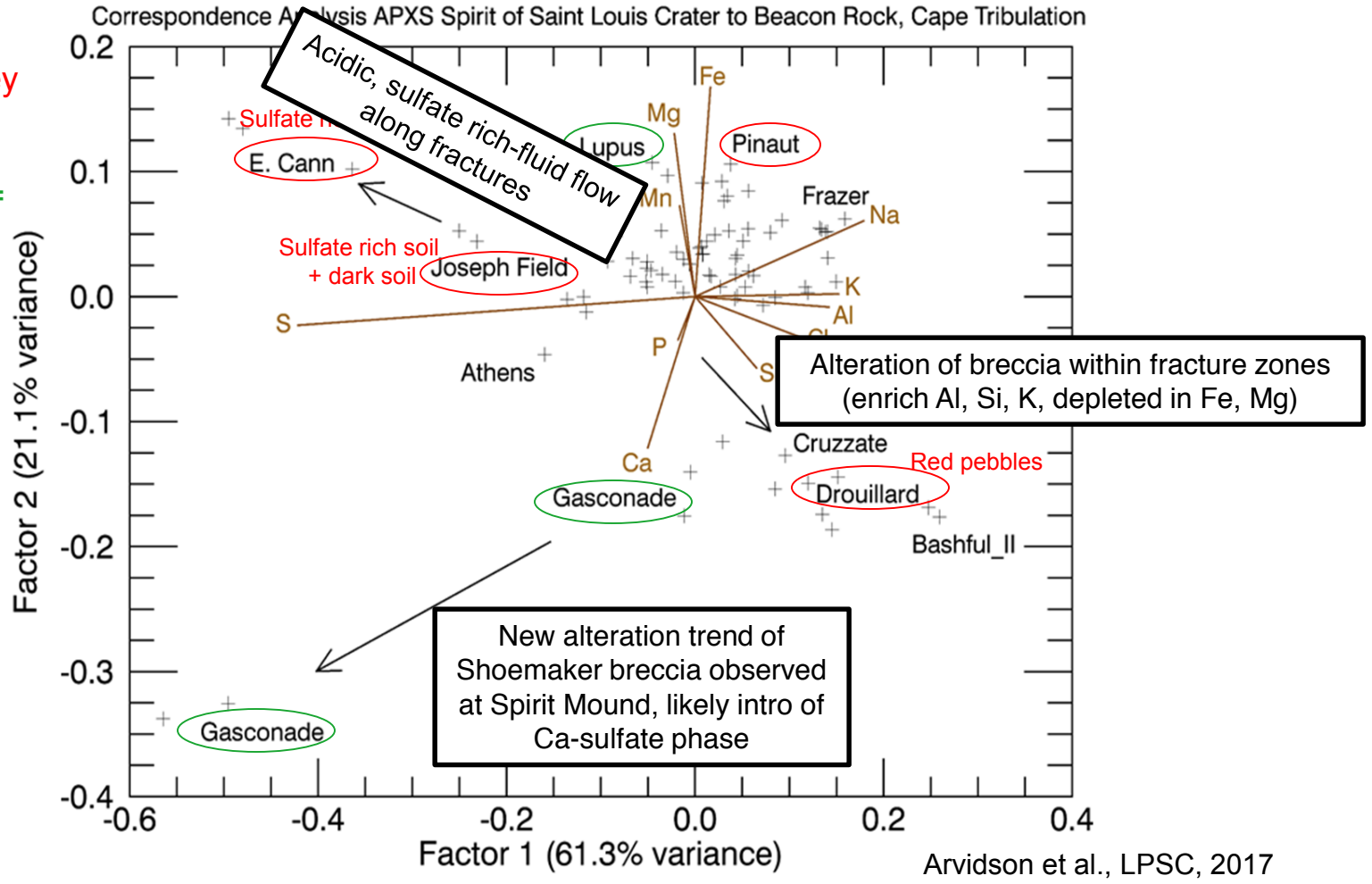
- Adds to growing understanding of complex fracture-controlled aqueous alteration history of Endeavour's rim

# Spirit Mound



Red circles = Marathon Valley floor targets

Green circles = Spirit Mound targets




Arvidson et al., LPSC, 2017

- Adds to growing understanding of complex fracture-controlled aqueous alteration history of Endeavour's rim

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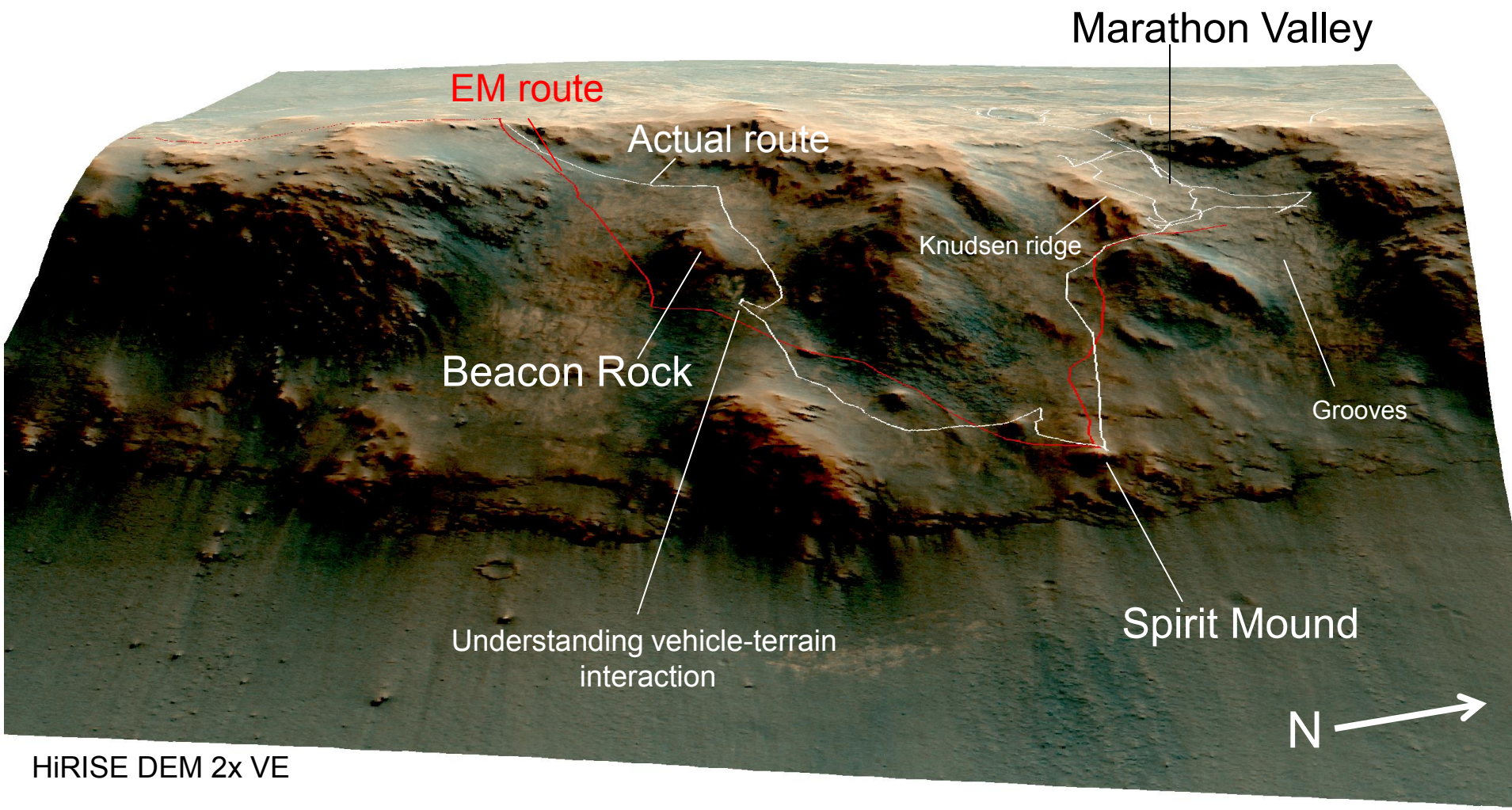
# Traverse Science

Mars Exploration Rover

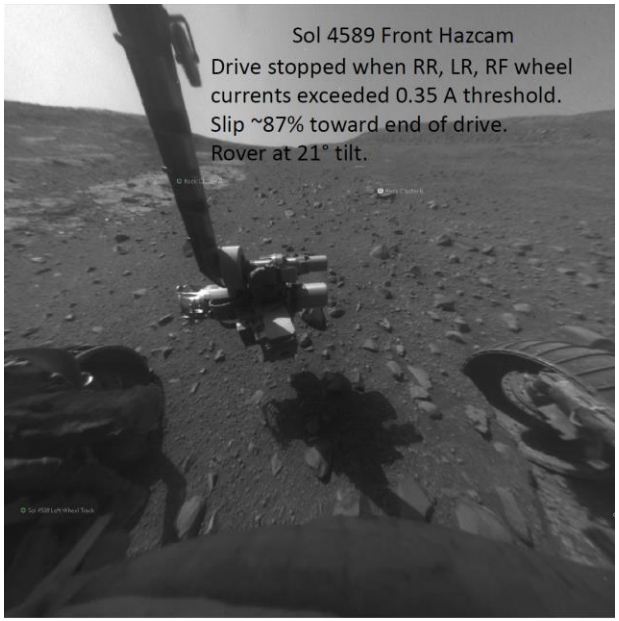



HiRISE DEM 2x VE

Continued operation of a healthy six-wheeled rocker-bogie suspension rover in very challenging martian terrain

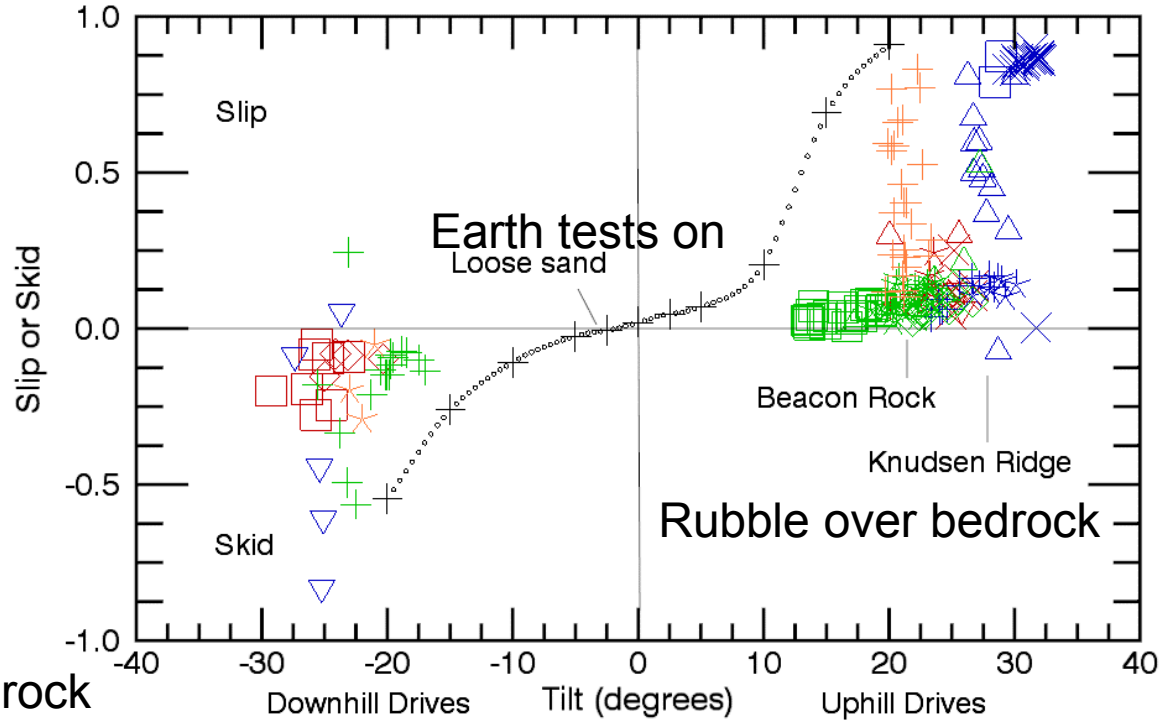
# Opportunity Mobility on Steep Slopes






Beacon Rock thin soil over bedrock

Nonlinear tilt-slip regimes

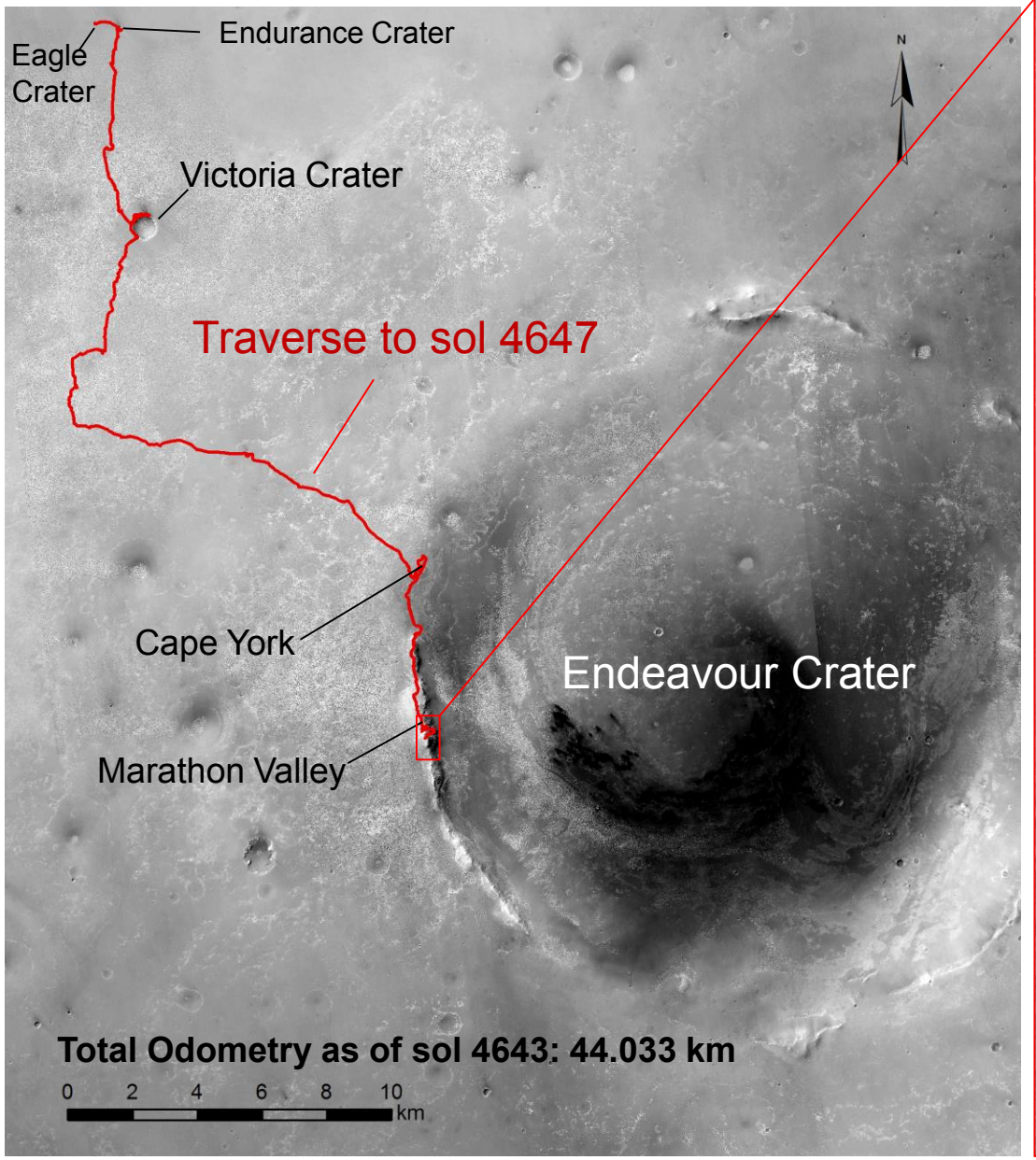


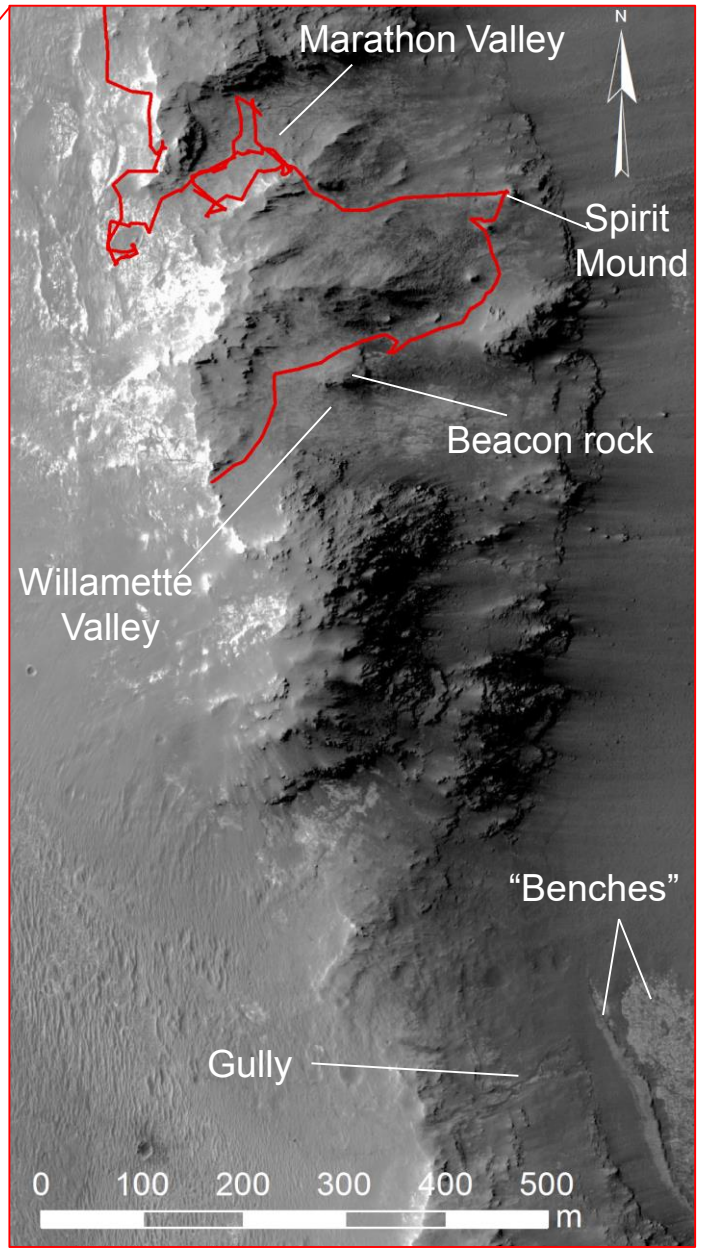

Arvidson et al., LPSC, 2017

Terrain properties play important role in tilt-slip regimes.
Opportunity telemetry data is helping improve understanding of terrain properties and numerical models of terrain-vehicle interactions.

# What's Next



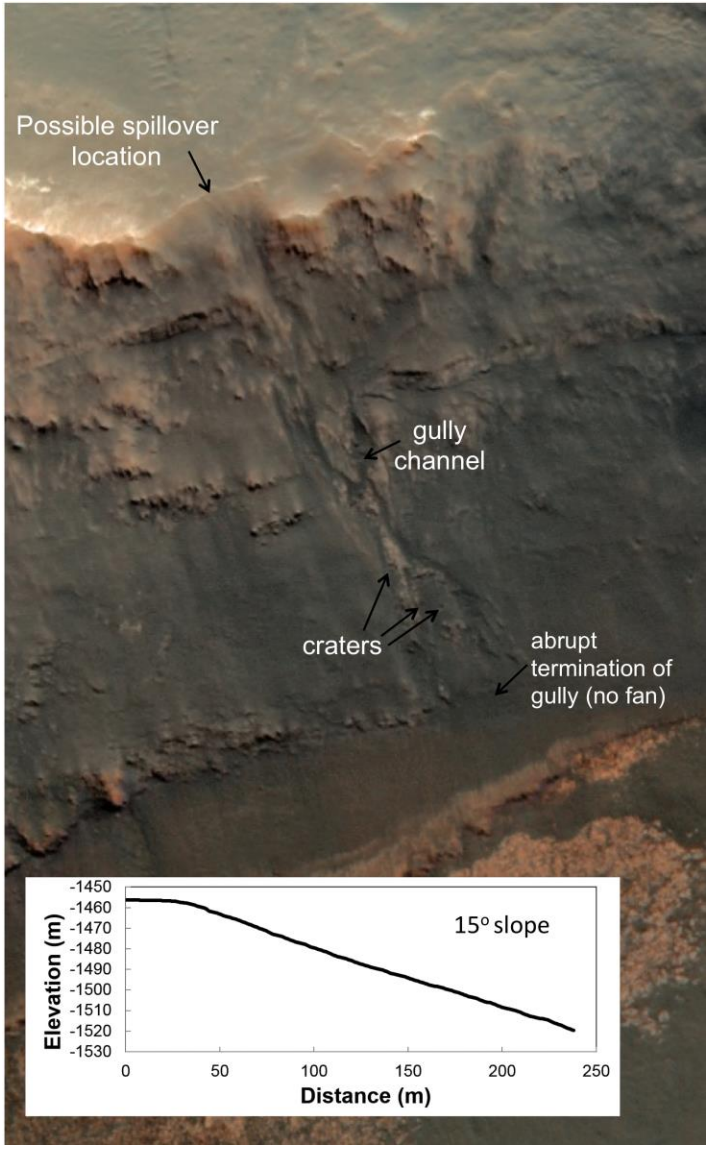

Endurance Crater
Eagle Crater
Victoria Crater
Traverse to sol 4647
Cape York
Endeavour Crater
Marathon Valley
N
Total Odometry as of sol 4643: 44.033 km
0 2 4 6 8 10
km


Marathon Valley
N
Spirit Mound
Beacon rock
Willamette Valley
"Benches"
Gully
0 100 200 300 400 500
m

# A fluid-carved gully



- Slightly less than 200 m long and at most a few tens of m wide
- Average gradient roughly 15˚
- Incised, anastomosing channels a few m wide arise from a break in slope
- Apparent distributary system, but no fan or delta
- It is not a recent feature:
  - Superimposed impact craters
  - Abrupt termination suggests post-formation truncation
- Opportunity will acquire detailed stereo imaging to test hypotheses about feature's origin



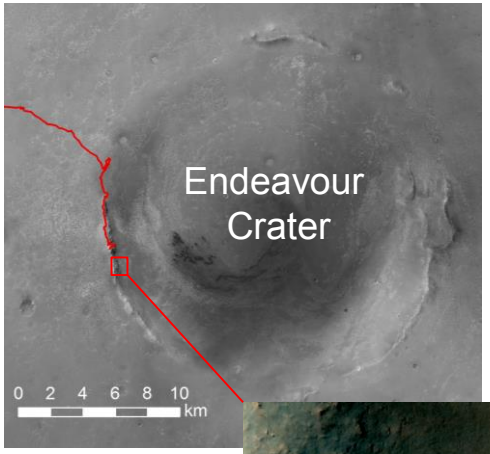
# The "Benches"

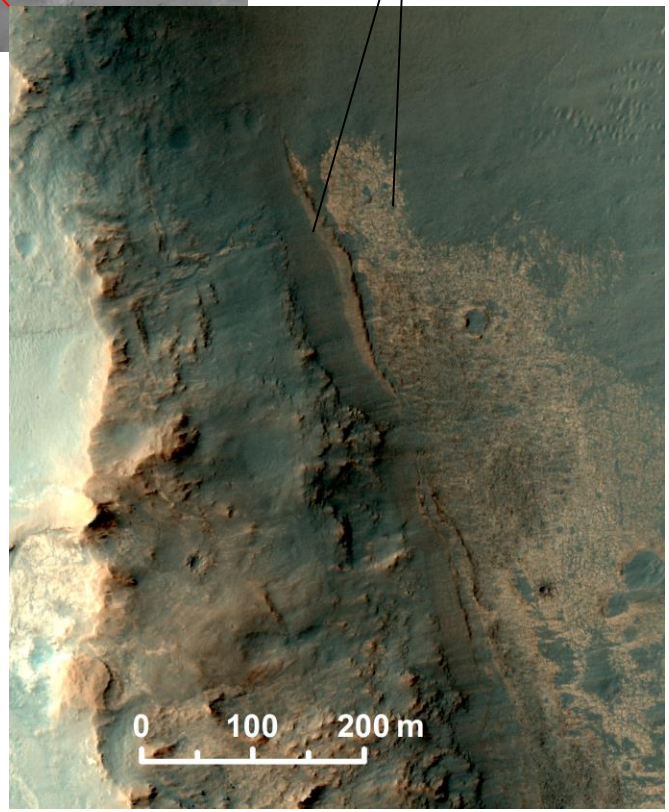


- Waters emerging from the inner walls and the floor of Endeavour would have been spatially and perhaps temporally different in origin from those outside the crater, percolating through different source rocks and perhaps persisting longer.

- Rocks at low elevations inside Endeavour crater could also have experienced different aqueous diagenetic histories than those outside the crater.

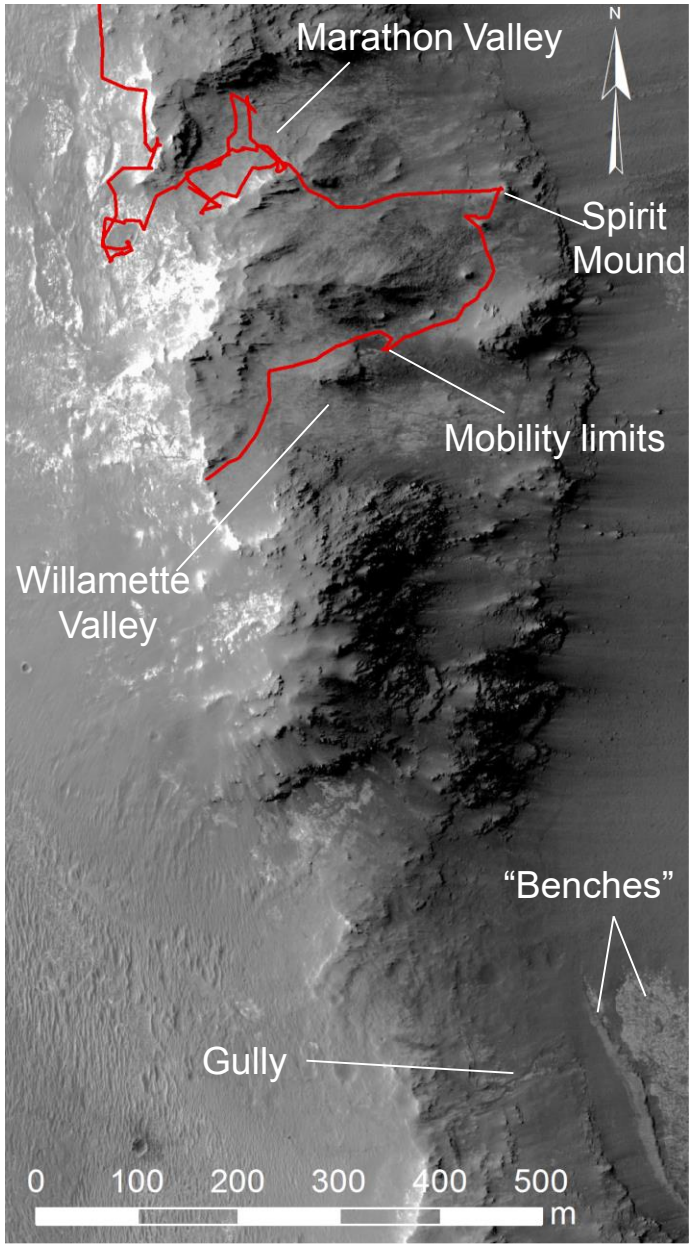
- Opportunity will investigate geometry, chemistry and texture of sedimentary rocks inside Endeavour crater to test models of diagenesis and groundwater flow and emergence.



# Conclusions






- Opportunity's recent observations increasingly add to our understanding about the range and diversity of aqueous environments in Mars' history
- Opportunity is continuing to explore rim of Endeavour crater, with science focused on understanding:
  - Noachian bedrock that predates Endeavour crater
  - Sedimentary rocks inside Endeavour crater
  - Fluid-carved features on Endeavour's rim

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# Backup

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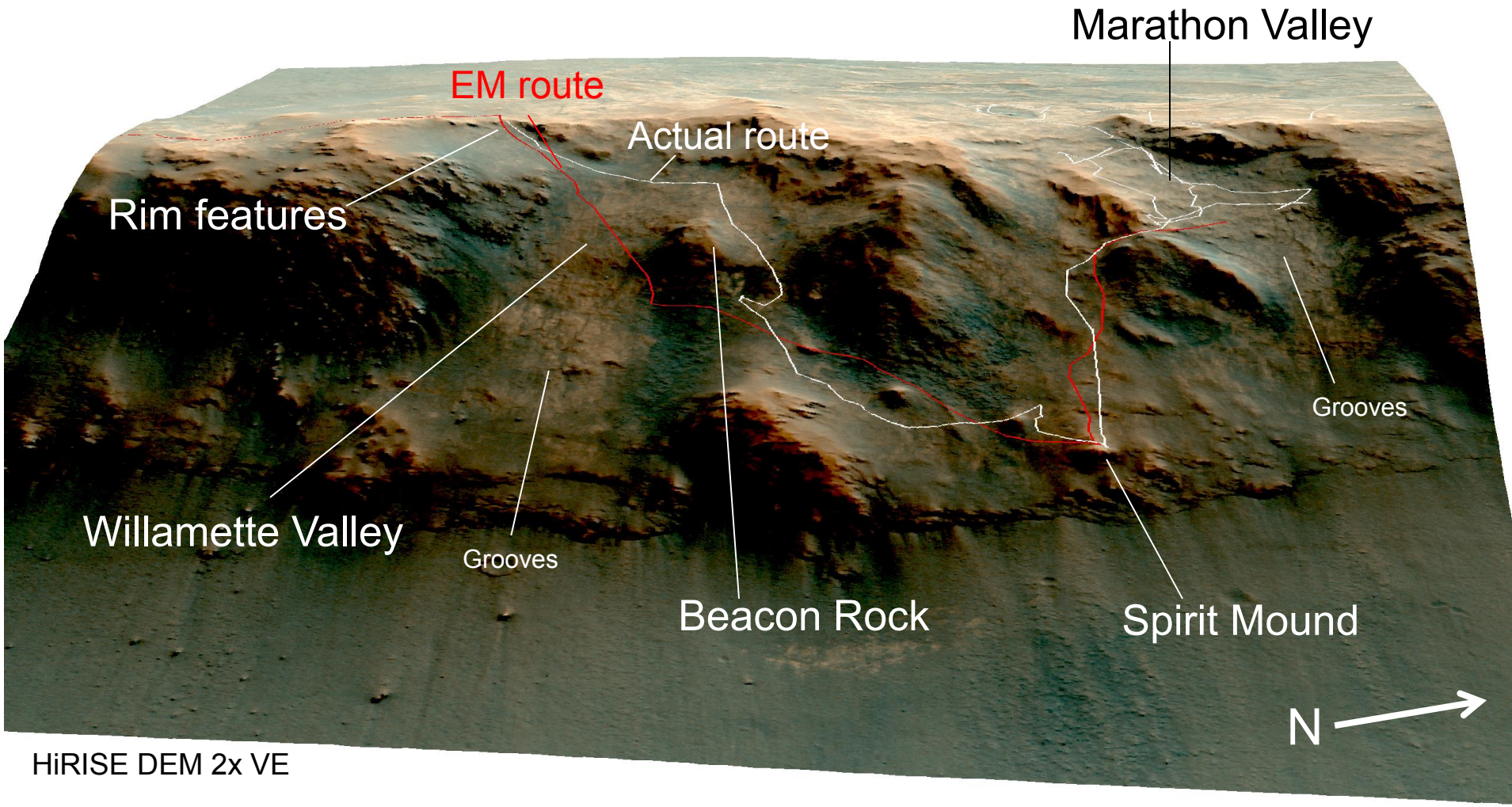
# Willamette Valley

Mars Exploration Rover




Opportunity currently located just beyond Willamette Valley

Show Rocheport pan if completed by next Thursday and v. briefly talk about cool groove/striation features?

# MER PDS Deliveries

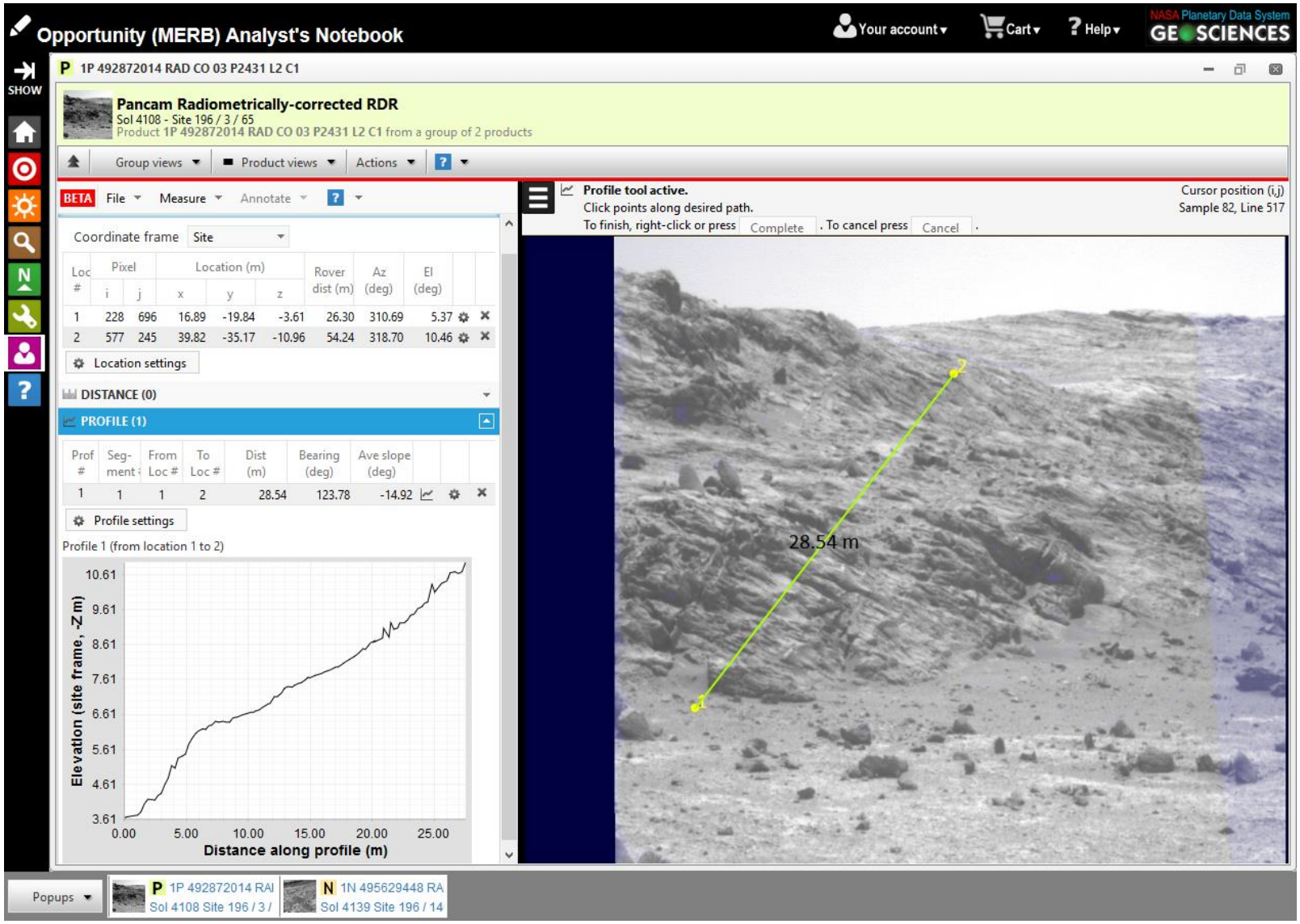


- The MER Project consistently continues to deliver complete, calibrated, validated science data products to the NASA Planetary Data System on a regular 90-day delivery schedule.
  - The table at right lists the completed and expected MER archive deliveries.

| Release | Release Date | Coverage |
|---|---|---|
| 54 | December 21, 2017 | Sols 4681-4770 |
| 53 | September 21, 2017 | Sols 4591-4680 |
| 52 | June 21, 2017 | Sols 4501-4590 |
| 51 | March 20, 2017 | Sols 4411-4500 |
| 50 | December 19, 2016 | Sols 4321-4410 |
| 49 | September 19, 2016 | Sols 4231-4320 |
| 48 | June 17, 2016 | Sols 4141-4230 |
| 47 | March 17, 2016 | Sols 4051-4140 |
| 46 | December 16, 2015 | Sols 3961-4050 |
| 45 | September 16, 2015 | Sols 3871-3960 |
| 44 | June 12, 2015 | Sols 3781-3870 |
| 43 | March 12, 2015 | Sols 3691-3780 |
| 42 | December 12, 2014 | Sols 3601-3690 |
| 41 | September 11, 2014 | Sols 3511-3600 |
| 40 | June 9, 2014 | Sols 3421-3510 |
| 39 | March 7, 2014 | Sols 3331-3420 |
| 38 | December 6, 2013 | Sols 3241-3330 |
| 37 | August 23, 2013 | Sols 3151-3240 |
| 36 | May 24, 2013 | Sols 3061-3150 |
| 33 | August 28, 2012 | Sols 2791-2880 |
| 34 | November 23, 2012 | Sols 2881-2970 |
| 35 | February 22, 2013 | Sols 2971-3060 |

# MER Analyst's Notebook





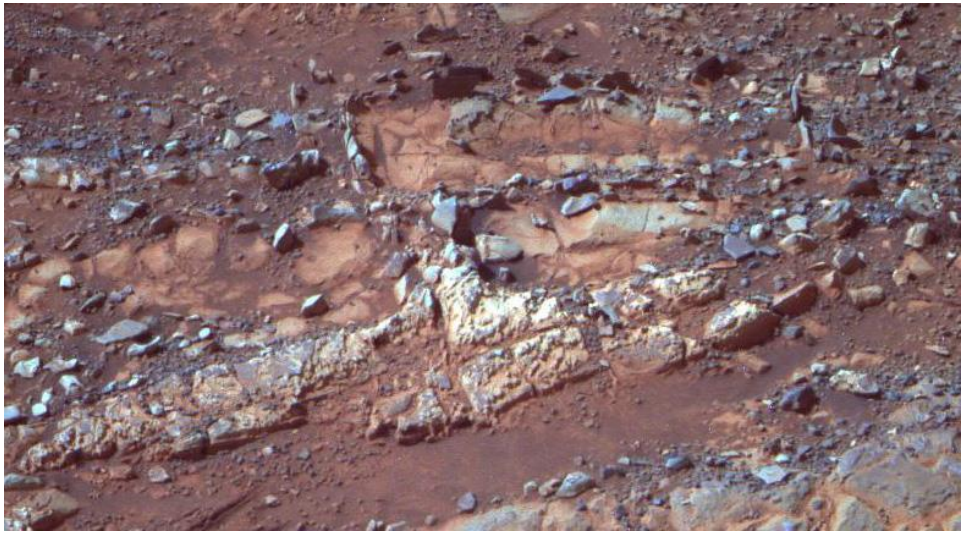
# Matijevic formation



## Ancient bedrock that predates Endeavour Crater

- The best cross-section exposure of Matijevic formation rocks:

- In one location at Matijevic Hill we also observed a fracture system bordered by an alteration zone with high concentrations of Al-phyllosilicates:



# Recent Science Highlights



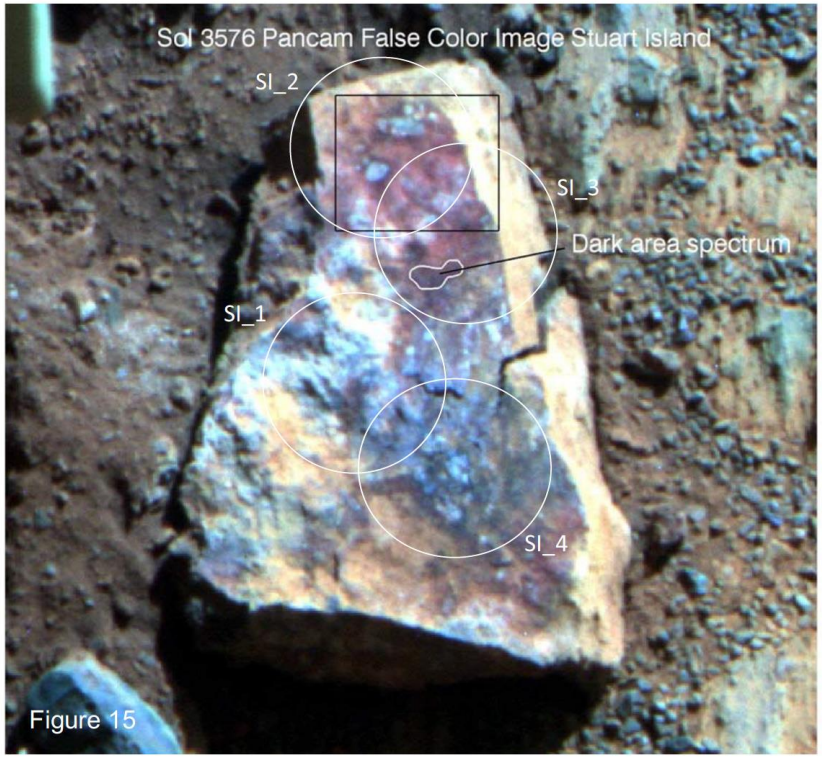
**High Concentrations of Manganese and Sulfur in Deposits on Murray Ridge, Endeavour Crater, Mars**

Raymond E. Arvidson[1], Steven W. Squyres[2], Richard V. Morris[3], Andrew H. Knoll[4], Ralf Gellert[5], Benton C. Clark[6], Jeffrey G. Catalano[1], Brad L. Jolliff[1], Scott M. McLennan[7], Kenneth E. Herkenhoff[8], Scott VanBommel[5], David W. Mittlefehldt[3], John P. Grotzinger[9], Edward A. Guinness[1], Jeffrey R. Johnson[10], James F. Bell III[11], William H. Farrand[6], Nathan Stein[1], Valerie K. Fox[1], Margaret A. G. Hinkle[1], Wendy M. Calvin[12] and Paulo A. de Souza Jr.[13]

Surfaces exposed by rover wheel action have the highest concentrations of Mn and S measured by Opportunity.

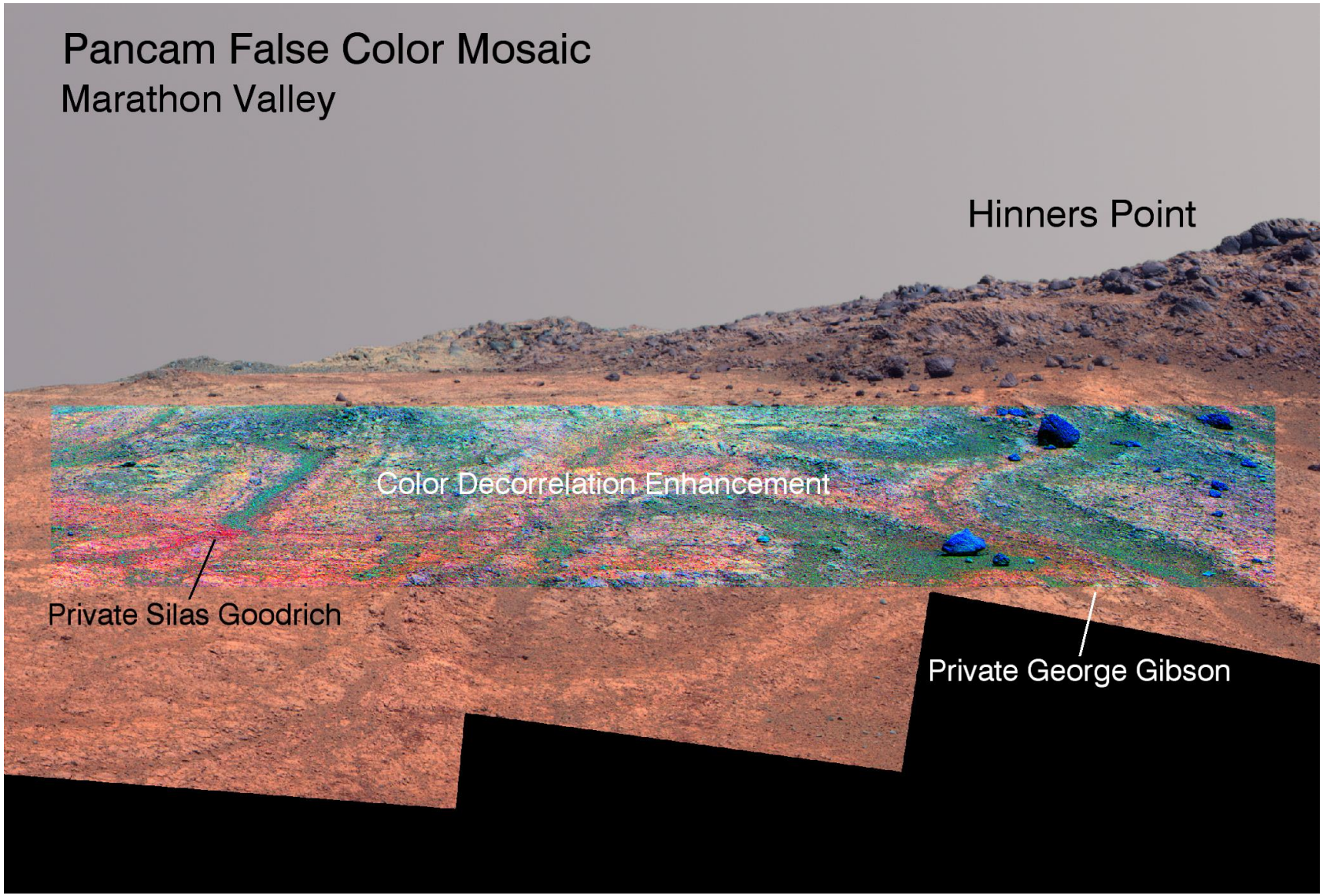
Pancam spectral properties are consistent with Mn oxides.

We infer subsurface precipitation of sulfate-dominated coatings, followed by partial dissolution and reaction with one or more strong oxidants to produce Mn oxides intermixed with sulfate-rich salts.



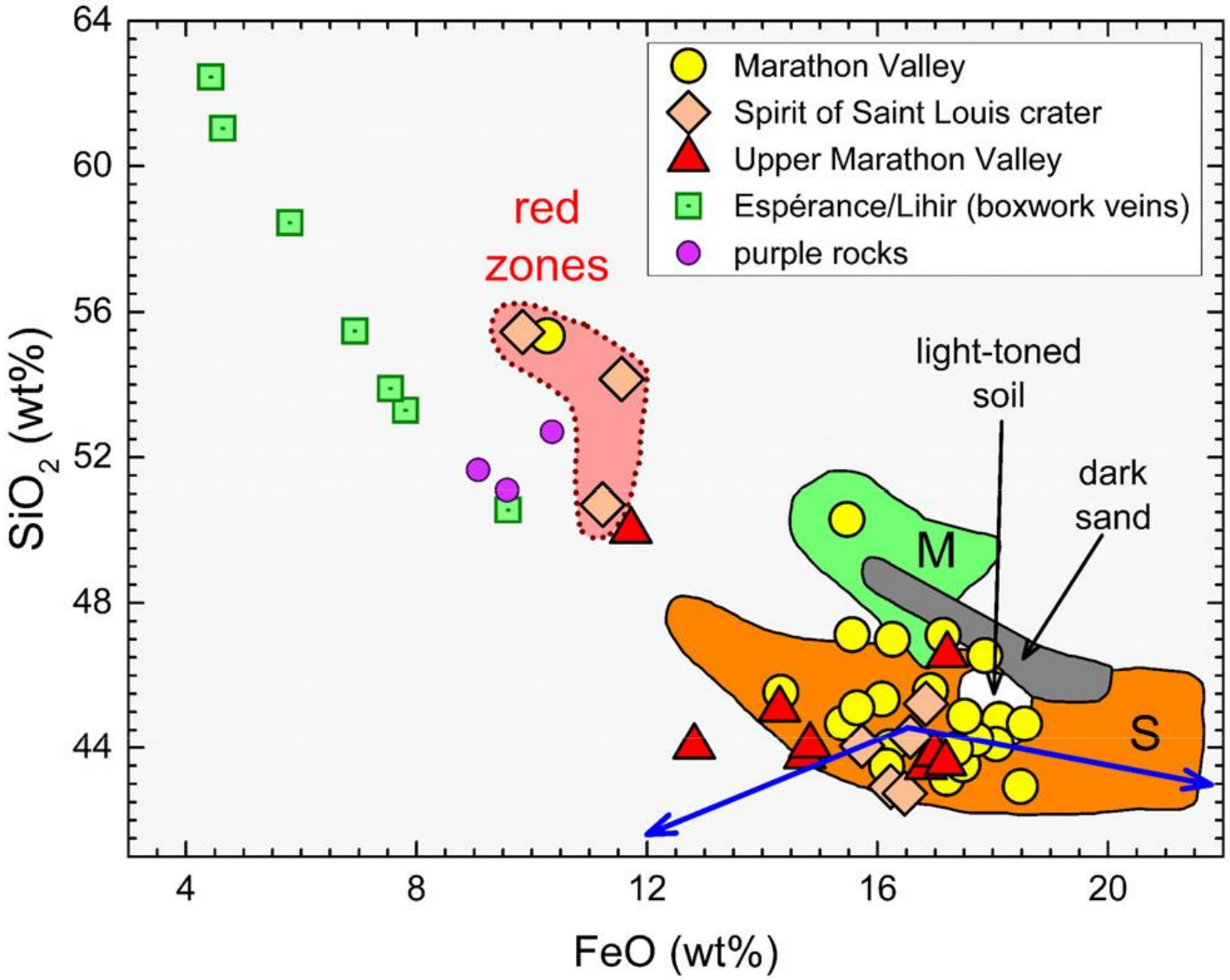
# Recent Science Highlights



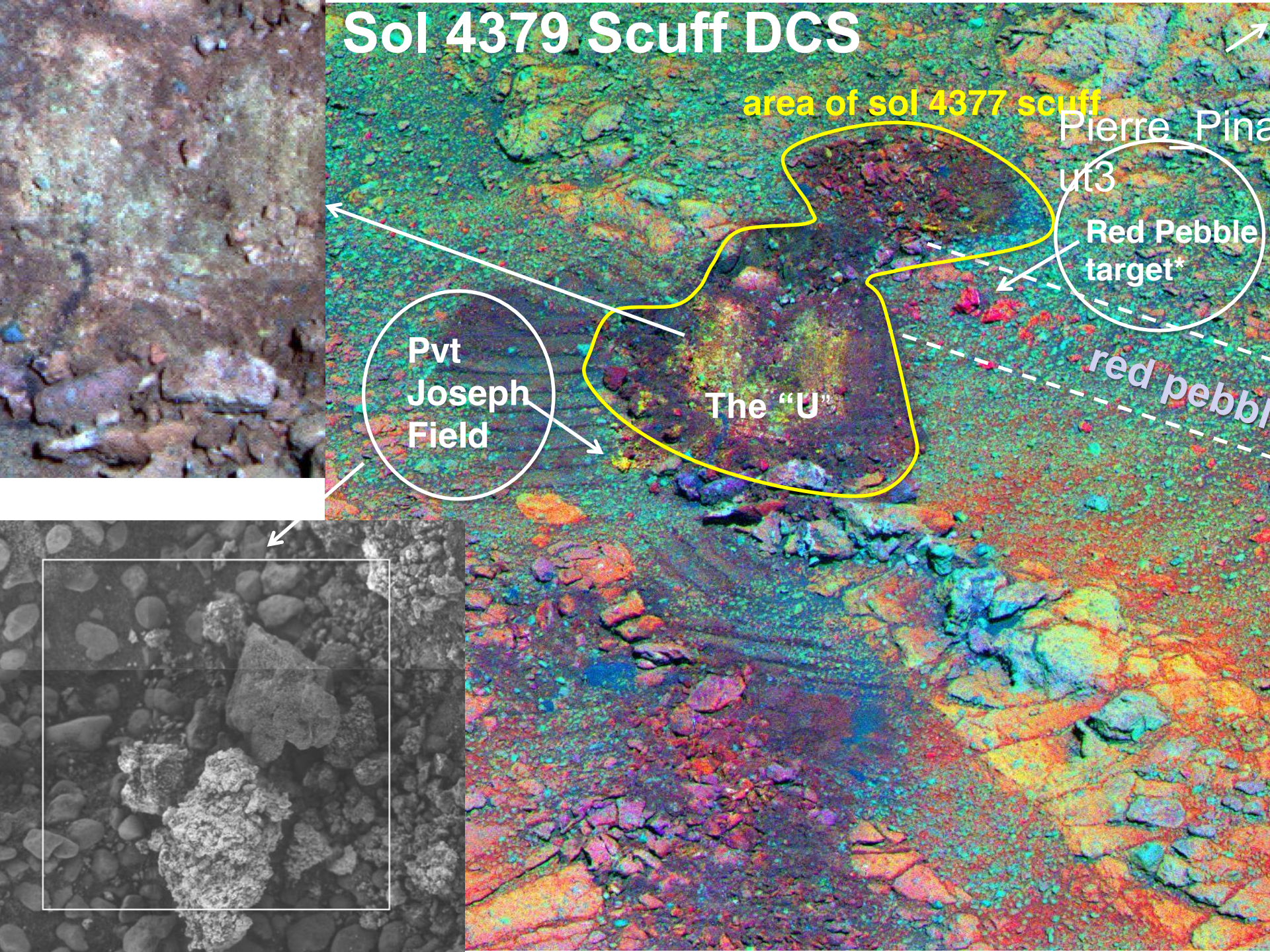


# Recent Science Highlights






(Blue arrows are trends toward nontronite and saponite)


Sol 4379 Scuff DCS
area of sol 4377 scuff
Pierre_Pina
urt3
Red Pebble
target*
Pvt
Joseph
Field
The "U"
red pebbl